Search for lepton flavour violation at PSI and HERA

Ralph A. Eichler [a]

[a]Institute for Particle Physics ETH-Zurich, CH8093 Zurich, Switzerland

Present limits of lepton flavour violating processes mediated by the exchange of a leptoquark are presented. Data are taken from $ep \to \ell X$ at HERA and rare muon decays.

1. LEPTON FLAVOUR VIOLATION THROUGH EXCHANGE OF AN EXOTIC HEAVY PARTICLE

In the minimal version of the Standard Model (SM), where only one Higgs doublet is included and massless neutrinos are assumed, lepton flavour violation (LFV) does not occur as a consequence of gauge invariance and the renormalizability of the Lagrangian. The observation of finite neutrino mass implies that lepton flavour is certainly not conserved. Observable effects are predicted in many extensions of the SM such as SUSY models, where the same Yukawa coupling constant among the Higgs doublet, lepton doublets and right handed neutrinos are responsible for ν-oscillations and LFV processes. In general, searches for rare processes could probe new interactions at high energy. The muon is particularly well suited since its long lifetime allows long observation times in $\mu \to e$ transitions like neutrinoless $\mu \to e$ decay in bound state μ-nucleus systems or rare decays like $\mu \to e\gamma, eee$. But also high energy scattering reactions like $ep \to \mu X$ probe LFV through the exchange of a virtual heavy boson. One class of bosons carry both colour and electric charge and connect quarks and leptons depicted in Figure 1b,c and they carry the generic name lepto-quark (LQ). Lepto-quarks have fermion number F=3B-L of zero or two, where B=baryon number and L=lepton number is denoted. Such exotic heavy particles appear e.g. in SUSY models with R-parity breaking, where the R-parity is defined as $(-1)^{F+2S}$ with S=0,1 the spin of the LQ, in models of quark-lepton substructure and in all unified models such as SU(5). For a modern review of the many different models see [1].

Electron-proton scattering at the HERA storage ring probes both the real production of LQ with the invariant lepton-quark(jet) as an observable or virtual LQ exchange for masses $m_{LQ} > \sqrt{s_{ep}} = 300$ GeV.

In the Buchmüller-Rückl-Wyler model [2], with B and L conservation and SU(3)×SU(2) ×U(1) invariant couplings to quark-lepton pairs, leptoquarks fit into three isospin families (singlet, doublet, triplet) and two spin states (scalar (S=0) and vector (S=1)). Processes in Fig. 1b,c are proportional the coupling constants λ with indices for the lepton generation l_j, l_n, lepton chirality L, R, quark generation q_i, q_k, and mass of LQ M_{LQ}

$$4\sqrt{2}G_{eff} = \lambda^{L(R)}_{l_j q_i} \lambda^{L(R)}_{l_n q_k} / M^2_{LQ}.$$

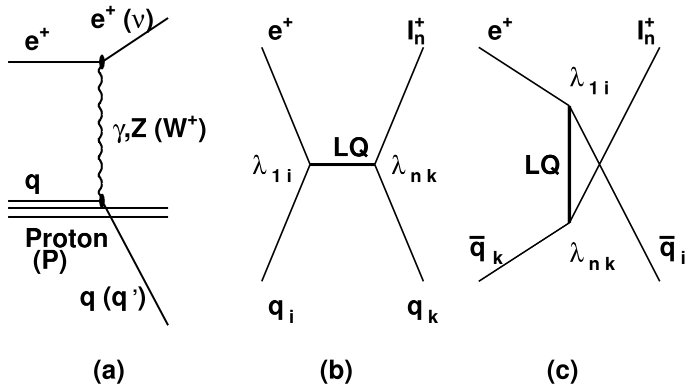

Figure 1. Diagrams of (a) deep-inelastic scattering; (b) s-channel and (c) u-channel exchange of a leptoquark with fermion number F=0. Diagrams involving $|F| = 2$ leptoquarks are obtained from (b) and (c) by exchanging q and $\bar{q}$

The quantity G_{eff} is a generalized four fermion coupling and will be compared with the Fermi coupling constant $4\sqrt{2}G_F = g^2/m_W^2$.

In following we restrict to $e \leftrightarrow \mu$ and $e \rightarrow \tau$ lepton flavour violating transitions and quote limits for the ratio G_{eff}/G_F in LQ models from HERA (ep scattering) and μ-decay experiments (PSI, Los Alamos).

2. EVENTS WITH ONE ISOLATED LEPTON AND A HADRON-JET (H1)

At HERA the H1 collaboration has searched for events with an isolated lepton and a hadronic jet. With an integrated luminosity of 37 pb^{-1} six events were found, one $e^+p \rightarrow e^-X$ and five events $e^+p \rightarrow \mu^{\pm}X$ [3]. All six events happen to have significant missing transverse energy which would be expected from $e^+p \rightarrow WX$ production. A careful analysis reveals, that the events are kinematically not compatible with the LQ hypothesis $eq \rightarrow \mu q', \tau q'$ and three of the events occupy a region of phase space which is not favoured by W-production. It remains a mystery, if these events are a statistical fluctuation or a signal for new physics. From the non-observation of resonant production of LQ or a significant excess of events over expectations we deduce a limit on the coupling constants and mass expressed by the ratio G_{eff}/G_F shown in Table 1.

Limits depend on isospin and spin of the LQ and detailed numbers are given in [4] by H1. Similar studies have been done by the ZEUS collaboration [5]. Except for $i = k = 1$ where the decay $\tau \rightarrow \pi e$ has an order of magnitude larger sensitivity, HERA gives in most cases, shown in Table 1, the best limits.

3. RARE PROCESSES WITH MUONS

The long muon lifetime of $\tau_\mu = 2.2\ \mu s$ make muon decays the most sensitive probe for $e \rightarrow \mu$ transitions. We show in Table 2 the corresponding limit on the ratio G_{eff}/G_F.

From the numbers it is evident, that LFV transitions $\mu \rightarrow e$ are much more restricted than $e \rightarrow \tau$ transitions.

Table 1
Limits for G_{eff}/G_F for $e \to \tau$ transitions ($j = 1, n = 3$) mediated by LQ exchange (from H1-experiment at HERA [4]). Limits may vary according to isospin of the LQ and are indicated by the range of values.

	F=0	F=0	F=2	F=2
i,k	scalar LQ	vector LQ	scalar LQ	vector LQ
1,1	0.32 - 0.53	0.05 - 0.13	0.11 - 0.27	0.15 - 0.26
1,2	0.15 - 0.54	0.12 - 0.15	0.35 - 0.39	0.41 - 0.67
1,3	0.56	0.17	0.19 - 0.38	0.72
2,1	0.81 - 1.29	0.085 - 0.17	0.12 - 0.29	0.15 - 0.27
2,2	0.085 - 1.54	0.12 - 0.29	0.20 - 0.57	0.45 - 0.78
2,3	1.20	0.30	0.22 - 0.45	0.81
3,1	1.37	0.19	0.16 - 0.33	0.27
3,2	1.63	0.22	0.29 - 0.59	0.61
3,3	1.97	0.39	0.37 - 0.74	1.03

Table 2
Limits for G_{eff}/G_F for $\mu \to e$ transitions ($j = 2, n = 1$) mediated by LQ exchange ($F = 0$). Limits may vary according to isospin of the LQ and are indicated by the range of values. Experimental limits on branching ratios (BR) are from [6,8,9,7]

process	BR limit	i,k	scalar LQ	vector LQ
$\mu^- Ti \to e^- Ti$	$6 \cdot 10^{-13}$	1,1	$(2.2 - 6.5) \cdot 10^{-6}$	$(0.9 - 2.2) \cdot 10^{-6}$
$\mu^+ \to e^+ \gamma$	$1 \cdot 10^{-11}$	2,2	$2.4 \cdot 10^{-4}$	0.03 - 0.34
		3,3	–	$4.8 \cdot 10^{-4}$
$\mu^+ \to e^+ e^- e^+$	$1 \cdot 10^{-12}$	-	$3.4 \cdot 10^{-4}$	
$\mu^+ e^- \to \mu^- e^+$	$8 \cdot 10^{-11}$		$3 \cdot 10^{-3}$	

4. NEW PROPOSAL TO SEARCH FOR $\mu \to e\gamma$ AT PSI

Depending on a specific model, $\mu \to e$ conversion or $\mu \to e\gamma$ are more sensitive to new physics and searches of both processes should be continued as far as possible. A new experiment for the search for the decay $\mu \to e\gamma$ is in preparation with a planned sensitivity of 10^{-14} [10]. The setup is depicted in Fig. 2. A novel photon detector is proposed using scintillation light produced in a liquid Xenon volume and viewed by 800 photomultipliers. An energy resolution of 2% FWHM at 52 MeV and 73% detection efficiency, time resolution of better than 100 ps and position resolution of order 4 mm are expected. The proposal was accepted in July 1999.

5. SUMMARY

Sensitive limits were presented for LFV transition via Leptoquarks. HERA gives best limits for $e \to \tau$ transitions for most types of leptoquarks while low energy μ-decay experiments are by far most sensitive for $e \to \mu$ transitions with diagonal couplings (i=k), although HERA contributes also here to some of the limits.

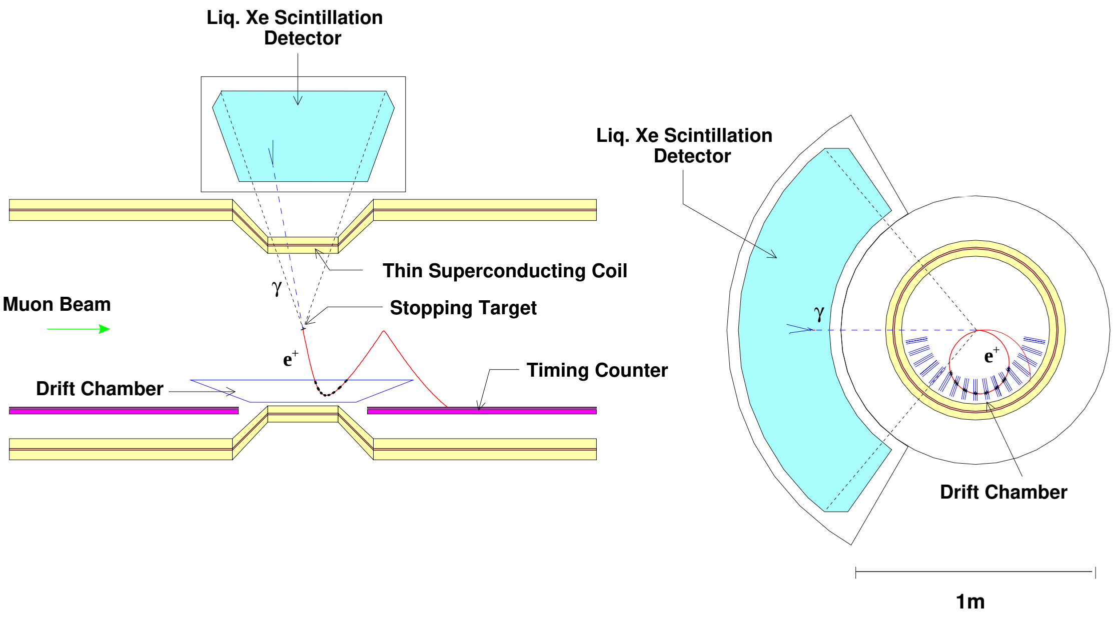

Figure 2. Setup of a new experiment to search for the decay $\mu \to e\gamma$ with an anticipated sensitivity of 10^{-14}.

Future plans at Paul Scherrer Institute, Switzerland are the search for $\mu \to e$ conversion with sensitivity of O(10^{-13}) and a new search for $\mu \to e\gamma$ with sensitivity of O(10^{-14}). Also planned is a search for electric dipole moment of the neutron with sensitivity of O(10^{-27}) ecm.

The HERA experiments are presently analysing 18 pb^{-1} of e^-p scattering data taken 1998/1999, which gives increased sensitivity to other isospin and fermion number LQ. In the shutdown during the year 2000, minibeta quadrupole magnets will be installed at the interaction region with the goal to increase the luminosity by a factor of five. The spin rotators installed simultaneously to produce longitudinal polarised e$^-$/e$^+$ beams will help to pinpoint new physics if discovered.

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